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Atty. Docket No.: GEML 4420-3

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Lynne M. Milliot

Lynne M. Milliot 11 April 2005

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:

Russell CHILDS et al.

Application No. 10/734,110

Confirmation No. 4858

Filed: 15 December 2003

Title: **INTEGRATED OPTICAL DEVICE**

Group Art Unit: 2883

Examiner: Joanne H. KIM

CUSTOMER NO. 22470

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TRANSMITTAL OF PRIORITY DOCUMENT

Sir:

Enclosed for filing in the subject application is a certified copy of the following document upon which this application claims priority: GB Application No. 0019883.8, filed 11 August 2000.

Respectfully submitted,

Warren S. Wolfeld

Date: 11 April 2005

Warren S. Wolfeld, Reg. No. 31,454

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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	GEML 4420-3
First Inventor	Russell Childs
Title	Integrated Optical Device
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: **Commissioner for Patents, P.O. Box 1450, Alexandria VA 22313-1450**

1. ☐ Fee Transmittal Form (e.g., PTO/SB/17) *(Submit an original and a duplicate for fee processing)*
2. ☐ Applicant claims small entity status. See 37 CFR 1.27.
3. ☐ Specification [*Total Pages* ____] *(preferred arrangement set forth below)*
   - Descriptive title of the invention
   - Cross Reference to Related Applications
   - Statement Regarding Fed sponsored R & D
   - Reference to sequence listing, a table, or a computer program listing appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
4. ☐ Drawing(s) (*35 U.S.C. 113*) [*Total Sheets* ____]
5. Oath or Declaration [*Total Sheets* ____]
   a. ☐ Newly executed (original or copy)
   b. ☐ Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional with Box 18 completed)*
      i. ☐ DELETION OF INVENTOR(S) Signed statement attached deleting inventor(s) name in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. ☐ Application Data Sheet. See 37 CFR 1.76
7. ☐ CD-ROM or CD-R in duplicate, large table or Computer Program *(Appendix)*
8. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   a. ☐ Computer Readable Form (CRF)
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ACCOMPANYING APPLICATION PARTS

9. ☐ Assignment Papers (cover sheet & document(s))
10. ☐ 37 CFR 3.73(b) Statement *(when there is an assignee)* ☐ Power of Attorney
11. ☐ English Translation Document *(if applicable)*
12. ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
13. ☐ Preliminary Amendment
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17. ☐ Other: ....

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in the first sentence of the specification following the title, or in an Application Data Sheet under 37 CFR 1.76:*

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: ....

Prior application information: *Examiner* ________ *Art Unit:* ________

For CONTINUATION OR DIVISIONAL APPS only; The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

19. CORRESPONDENCE ADDRESS

☑ Customer Number: 22470 **OR** ☐ Correspondence address below

Name					
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City		*State*		*Zip Code*	
Country		*Telephone*		*Fax*	

Name (Print/Type)	Warren S. Wolfeld	*Registration No. (Attorney/Agent)*	31,454
Signature	Warren S. Wolfeld	*Date*	11 April 2005

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The Patent Office
Concept House
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NP10 8QQ

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation and Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein together with the Statement of inventorship and of right to grant of a Patent (Form 7/77), which was subsequently filed.

that the application is now proceeding in the name as identified herein.

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GB 2366394

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KYMATA NETHERLANDS B.V.,
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7521 PV Enschede,
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Incorporated in the Netherlands,

[ADP No. 08223240001]

and

ALCATEL OPTRONICS UK LIMITED,
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Incorporated in the United Kingdom,

[ADP No. 08279440001]

GB0019883.8

By virtue of a direction given under Section 30 of the Patents Act 1977, the application is proceeding in the name of

ALCATEL OPTRONICS UK LIMITED
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[ADP No. 08279440001]

Patents Form 1/77

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Cardiff Road
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Request for a grant of a patent

THE PATENT OFFICE
11 AUG 2000
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14AUG00 E560483-14 D02246
P01/7700 0.00-0019883.8

1. Your reference	P009610GB	
2. Patent application number *(The Patent Office will fill in this part)*	0019883.8	11 AUG 2000
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	KYMATA LIMITED STARLAW PARK STARLAW ROAD LIVINGSTON EH54 8SF UNITED KINGDOM	BBV SOFTWARE BV KYMATA NETHERLANDS COLLEUSSEUM 11 7521 PV ENSCHEDE NETHERLANDS
Patents ADP number *(if you know it)*	763328002	08164188001
If the applicant is a corporate body, give the country/state of its incorporation		
4. Title of the invention	INTEGRATED OPTICAL DEVICE	
5. Name of your agent *(if you have one)*	D YOUNG & CO	
"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)	21 NEW FETTER LANE LONDON EC4A 1DA	
Patents ADP number *(if you know it)*	59006	59006

AC 1/77 5/9/02

21/11/01

6. If you are declaring priority from one or more earlier patent applications, give the country and date of filing of the or each of these earlier applications and *(if you know it)* the or each application number	Country	Priority application number *(if you know it)*	Date of filing *(day/month/year)*
1st			
2nd			
3rd			

7. If this application is divided or otherwise derived from an earlier UK application, give the number and filing date of the earlier application	Number of earlier application	Date of filing (day/month/year)

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a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
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9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

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Description	6
Claim(s)	2
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10. If you are also filing any of the following, state how many against each item

Priority Documents	0
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Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	0
Request for preliminary examination and search *(Patents Form 9/77)*	1
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11. I/We request the grant of a Patent on the basis of this application.

Signature

D Young & Co

D YOUNG & CO
Agents for the Applicants

Date
11 Aug 2000

12. Name and daytime telephone number of person to contact in the United Kingdom — James Turner — 023 8071 9500

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7/77 e2

Statement of inventorship and of right to grant of a patent

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

1.	Your reference	P/009610.GB - JM
2.	Patent application number *(if you know it)*	0019883.8
3.	Full name of the or of each applicant	KYMATA LIMITED BBV SOFTWARE BV
4.	Title of the invention	INTEGRATED OPTICAL DEVICE
5.	State how the applicant*(s)* derived the right from the inventor*(s)* to be granted a patent	BY VIRTUE OF EMPLOYMENT
6.	How many, if any, additional Patents Forms 7/77 are attached to this form? *(see note (c))*	0
7.		I/We believe that the person*(s)* named over the page *(and on any extra copies of this form)* is/are the inventor*(s)* of the invention which the above patent application relates to. Signature Date 17 SEP 2001 D Young & Co (Agents for the Applicants)
8.	Name and daytime telephone number of person to contact in the United Kingdom	Julia Mills *Julia Mills* 023 8071 9500

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67329-SB-15

Enter the full names, addresses and postcodes of the inventors in the boxes and underline the surnames

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Reminder

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INTEGRATED OPTICAL DEVICE

This invention relates to integrated optical devices.

In the development of optical networks, so-called integrated optical components using waveguides established on a planar substrate are being extensively investigated.

In integrated optical devices, waveguide "cores" are deposited onto a substrate (or more generally onto an undercladding formed on the substrate) and are then covered by an overcladding layer. The refractive indices and other optical properties of the core and cladding materials are set to provide an appropriate waveguiding function. The skilled man will appreciate that terms such as "undercladding", "overcladding", "beneath" and the like are used merely for convenience of the description and do not imply any particular orientation of the device during fabrication or use.

A problem which can arise in integrated devices of this nature is that of birefringence. Although the mechanism by which the birefringence arises has not been proven, it is thought to result from differences in thermal expansion properties between layers in the device structures, which cause stresses to build up when the device is cooled after sintering or annealing.

Various possible solutions to this problem are summarised, with references, in the paper "Birefringence free planar optical waveguide made by flame hydrolysis deposition (FHD) through tailoring of the overcladding", Kilian et al, Journal of Lightwave Technology Vol. 18, No 2, February 2000. Mostly the previously proposed solutions involve altering the thermal properties of the overcladding, generally to try to match the thermal coefficient of expansion of the overcladding to that of the core, undercladding or substrate. A specific example of this technique is disclosed in US-A-5 930 439. While this aim can be achieved by careful choice of dopants, it has been found that the overcladding glass has to be so dopant-rich that it becomes very sensitive to moisture, leading to device unreliability.

An alternative approach is described in the paper "Penalty-free polarisation compensation of SiO_2/Si arrayed waveguide grating wavelength multiplexers using stress release grooves", Wildermuth et al, Electronics Letters Vol. 34, No 17, August 1998. Here, a stress-relieving groove is etched along either side of the waveguide cores. In the context of an arrayed waveguide grating (AWG) device having a large number of substantially parallel waveguide cores, this means interspersing those cores with deep grooves. This process is considered to be unattractive because of the need for a significant extra process step to etch

the grooves, the difficulty of aligning the groove etching with the waveguide cores, and the extra substrate area taken up by the grooves.

This invention provides a method of fabricating an integrated optical device on a substrate, at least a face of the substrate providing a first cladding layer, the method comprising the steps of:

(i) forming a core material layer on the first cladding layer;

(ii) etching the device in regions forming the complement of a desired waveguide core, the etching step removing material from the core material layer and at least some material from the first cladding layer so that the first cladding layer forms a mesa formation substantially covered by the waveguide core; and

(iii) forming a second cladding layer over the first cladding layer and waveguide core.

The invention provides a new method of fabrication and device structure which can lead to a reduced or substantially zero birefringence without the need for heavy doping of the cladding or a separate etching step.

As part of the core etching process, during which excess material of a core material layer is removed by etching (having applied masks so as to leave the core paths unetched), the etching is continued into the undercladding layer. This "over-etching" technique leaves a mesa formation beneath the core. When the overcladding is applied, it extends around the core (as before) but also to a small extent beneath the level of the core.

This arrangement has been found to affect the core birefringence. By selection of an appropriate over-etch depth (mesa height) a reduced or substantially zero core birefringence can be obtained.

The invention is applicable to substrates such as silicon or germanium, on which an undercladding layer is generally grown or deposited. Here, it is considered that the substrate with the undercladding layer already grown or deposited on it provides a substrate whereby "at least a face of the substrate provides a first cladding layer". However, it is not always necessary to grow or deposit an undercladding layer. An example here is a quartz substrate where the optical properties of the substrates itself are such that the core can be deposited directly on to the substrate. Again, because an upper layer of the substrate itself acts as the undercladding for light-guiding purposes, it is considered that such a substrate also provides a substrate whereby "at least a face of the substrate provides a first cladding layer.

Preferably the mesa formation has a height such that substantially zero core birefringence is obtained. For example, it is preferred that the mesa formation has a height

of at least 1μm, and more preferably between about 2μm and about 4μm. It is appreciated that a smaller degree of over-etching may have occurred in the past, for example to ensure that the core material was fully etched away.

Although the invention is applicable to many types of device, it is preferred that the substrate is a silicon substrate and/or the first cladding layer is predominantly silicon dioxide.

In order to achieve a lower mesa height for a desired birefringence performance, it is preferred that the linear coefficient of expansion of the material of the second cladding layer is greater than that of the material of the core material layer.

This invention also provides an integrated optical device comprising:

a substrate, at least a face of the substrate providing a first cladding layer, the first cladding layer including a mesa formation;

a waveguide core formed on the first cladding layer so that the waveguide core substantially covers the mesa formation; and

a second cladding layer formed over the waveguide core and the first cladding layer.

Embodiments of the invention will now be described with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

Figures 1a to 1f are schematic cross-sectional illustrations of process steps in the fabrication of part of an integrated optical device according to an embodiment of the invention;

Figure 2 is a graph of birefringence against over-etch depth as predicted by computer modelling for various material properties; and

Figure 3 is a graph of birefringence against over-etch depth as obtained by experiment.

Referring now to the drawings, Figures 1a to 1f are schematic cross-sectional illustrations of process steps in the fabrication of part of an integrated optical device according to an embodiment of the invention. In prototype investigations, a 40 channel arrayed waveguide grating (AWG) having a 100GHz channel spacing and 250μm output waveguide pitch was fabricated, but in other embodiments of the invention many types of optical signal handling devices may be fabricated using this technique, such as variable optical attenuators, optical switches or routers and/or optical filters. The technique is generally applicable to any integrated optical component using a waveguide structure.

Figure 1a schematically illustrates a silicon substrate 10 on which a 16μm thick thermal oxide undercladding layer 20 is grown. (It is noted that Figures 1a to 1f are highly schematic and in any event not to scale).

In Figure 1c, a layer of waveguide core glass 30 is deposited, for example by flame hydrolysis deposition (FHD). In a preferred embodiment, the layer 30 is 6μm thick after an annealing stage to consolidate the FHD-deposited material. A mask 40 is applied to mask the path of a desired waveguide core. The mask is preferably formed by photolithographically spinning and exposing a resist layer, followed by development and coating with a metal layer by evaporation. The resist and its cover of metal can be lifted off with acetone to leave the metal mask 40.

In Figure 1d, an etching step is carried out using conventional wet or dry etching techniques.

The etching step etches away parts of the core material layer 30 not covered by the mask 40, that is to say, regions forming the complement of the desired waveguide path are removed from the core material layer 30. This leaves a substantially square section (6μm x 6μm) core 50.

In a conventional fabrication process, the next step would be to remove the mask 40 and apply an overcladding layer to the structure of Figure 1d. In embodiments of the present invention, however, the etching process is continued further, still using the mask 40 to define regions to be etched.

As shown in Figure 1e, the etching process is carried on so that part of the undercladding layer 20 is etched away in regions not protected by the mask 40. This "over-etching" process leaves an undercladding layer 20 which is thinner across most of the device, but which forms a mesa formation 60 substantially covered by the core 50. The height of the mesa formation may also be equivalently referred to as an "over-etch depth" and may typically be in the range of 2μm to 3μm, but preferably in any event greater than 1μm.

Finally, in Figure 1f the mask 40 is removed by conventional techniques and the waveguide and undercladding are covered by an overcladding layer 70. In this prototype embodiment the overcladding layer 70 is 22μm thick (at its thickest) and is a glass formed by FHD deposition using $SiCl_4$, BCl_3 and $POCl_3$. The overcladding composition is such that its refractive index is roughly matched to that of the silica undercladding, and its thermal expansion is slightly higher than that of the silicon substrate (as measured by warpage of coated wafers).

Figure 2 is a graph of birefringence against over-etch depth as predicted by computer modelling for various material properties.

The effect that over-etching has on the birefringence of a single waveguide was simulated by Finite Element Modelling analysis to determine the stresses applied to the waveguide core. The ordinary and extraordinary refractive index changes were then calculated from the stresses. By means of perturbation calculations, the change in effective refractive index ($Neff_{TE} - Neff_{TM}$) was determined.

It was found that the effect of over-etching was influenced by the linear coefficient of expansion (lce) of the core and the cladding. So, in the computer modelling various combinations of lce values were used.

The following material parameters were used in the computer modelling. These are the values reported in the paper by Kilian et al referred to above.

	Symbol	Si	SiO2 undercladding	Overcladding	Core
Youngs' Modulus GPA)	E	169	72.5	70	65
Poisson ratio [-]	v	0.064	0.17	0.2	0.2
Linear coefficient of expansion [K^{-1}]	a	3.6E-6	1.2E-6	Varied (3.3-3.5) E-6	Varied (1.2-2.4) E-6

The lce of the overcladding was varied among three possible values, namely:

3.3×10^{-6}

3.4×10^{-6}

3.5×10^{-6}

Similarly, the lce for the core was modelled at three possible values, namely:

1.2×10^{-6}

1.8×10^{-6}

2.4×10^{-6}

giving nine curves in all. The vertical axis has been calibrated to represent wavelength splitting between the two polarisations, as used in the empirical results of Figure 3, so that a comparison can be made.

The results shown in Figure 2 indicate that birefringence depends substantially linearly on the over-etch depth. The slope of the dependence depends on the lce values of the core and the overcladding. An ideal over-etch depth is considered to be one where the relevant curve crosses the zero-birefringence axis.

In the graph of Figure 2, the legend indicates first the value of the overcladding lce (x 10^{-6}) followed by the value of the core lce (x10^{-6}). It can be seen that a zero birefringence is obtained for an over-etch depth of about 2 μm upwards using the example parameters. The lowest over-etch depth giving a zero birefringence in this model is obtained for a combination of high lce for the cladding and low lce for the core. This model ignores any stress influence due to neighbouring waveguides and also does not consider the index contrast which may have an influence on the ideal over-etch depth.

In order to test the theoretical results, a series of prototype devices constructed as described above were tested. The core birefringence was detected by measuring the filter response or passband for two polarisation states, one parallel to the plane of the substrate and one perpendicular, and detecting the wavelength splitting (in nm) between the two. The results are shown in Figure 3 which indicate the same generally linear dependence between birefringence and over-etch depth as that predicted by the FEM analysis, crossing the zero-birefringence axis at an over-etch depth of about 3μm.

CLAIMS

1. A method of fabricating an integrated optical device on a substrate, at least a face of the substrate providing a first cladding layer, the method comprising the steps of:

(i) forming a core material layer on the first cladding layer;

(ii) etching the device in regions forming the complement of a desired waveguide core, the etching step removing material from the core material layer and at least some material from the first cladding layer so that the first cladding layer forms a mesa formation substantially covered by the waveguide core; and

(iii) forming a second cladding layer over the first cladding layer and waveguide core.

2. A method according to claim 1, in which the mesa formation has a height of at least 1μm.

3. A method according to claim 2, in which the mesa formation has a height of between about 2μm and about 4μm.

4. A method according to any one of the preceding claims, comprising the step, before step (i), of forming the first cladding layer on the substrate.

5. A method according to claim 4, in which the substrate is a silicon substrate.

6. A method according to claim 4 or claim 5, in which the first cladding layer is predominantly silicon dioxide.

7. A method according to any one of the preceding claims, in which the height of the mesa formation is selected so as to give a substantially zero birefringence in the waveguide core.

8. A method according to any one of the preceding claims, in which the linear coefficient of expansion of the material of the second cladding layer is greater than that of the material of the core material layer.

9. An integrated optical device comprising:

a substrate, at least a face of the substrate providing a first cladding layer, the first cladding layer including a mesa formation;

a waveguide core formed on the first cladding layer so that the waveguide core substantially covers the mesa formation; and

a second cladding layer formed over the waveguide core and the first cladding layer.

10. A method of fabricating an integrated optical device, the method being substantially as hereinbefore described with reference to the accompanying drawings.

11. An integrated optical device substantially as hereinbefore described with reference to the accompanying drawings.

ABSTRACT

INTEGRATED OPTICAL DEVICE

An integrated optical device comprises a substrate, at least a face of the substrate providing a first cladding layer, the first cladding layer including a mesa formation; a waveguide core formed on the first cladding layer so that the waveguide core substantially covers the mesa formation; and a second cladding layer formed over the waveguide core and the first cladding layer.

Figure 2.

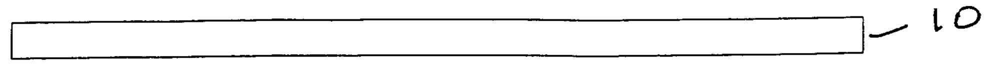


Fig. 1a

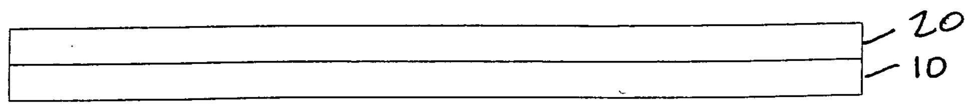


Fig. 1b

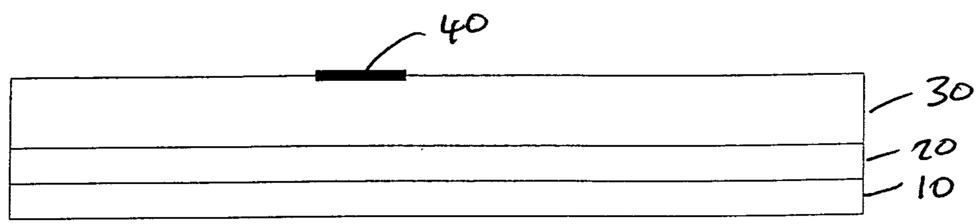


Fig. 1c

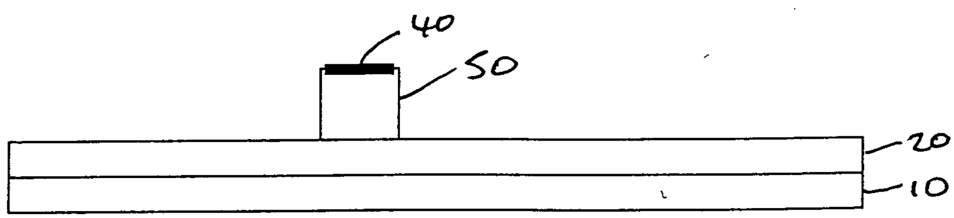


Fig. 1d

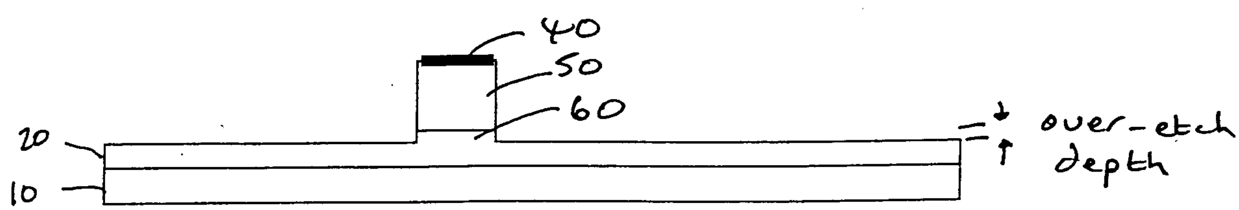


Fig. 1e

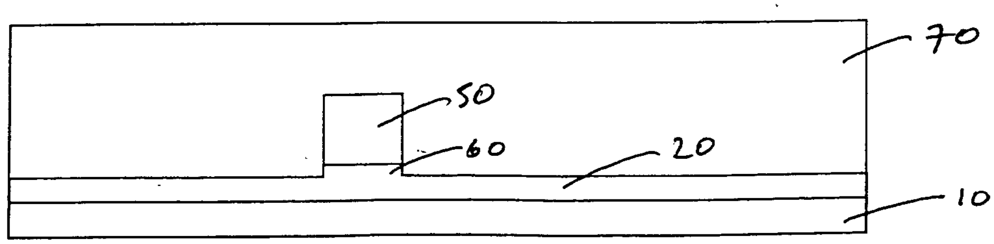
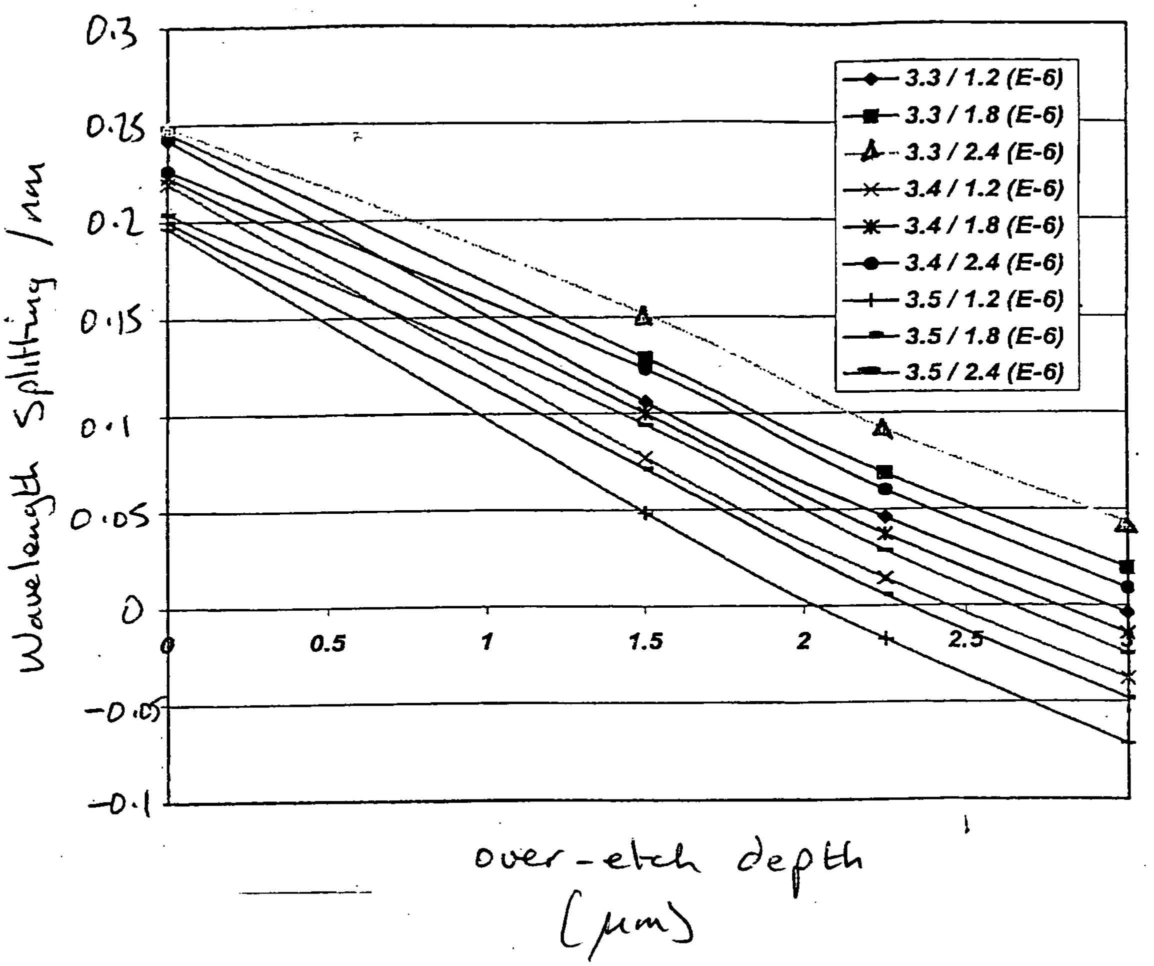


Fig. 1F

2/3



0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
Wavelength Splitting /nm
0
0.5
1
1.5
2
2.5
over-etch depth (μm)
3.3 / 1.2 (E-6)
3.3 / 1.8 (E-6)
3.3 / 2.4 (E-6)
3.4 / 1.2 (E-6)
3.4 / 1.8 (E-6)
3.4 / 2.4 (E-6)
3.5 / 1.2 (E-6)
3.5 / 1.8 (E-6)
3.5 / 2.4 (E-6)

Fig. 2

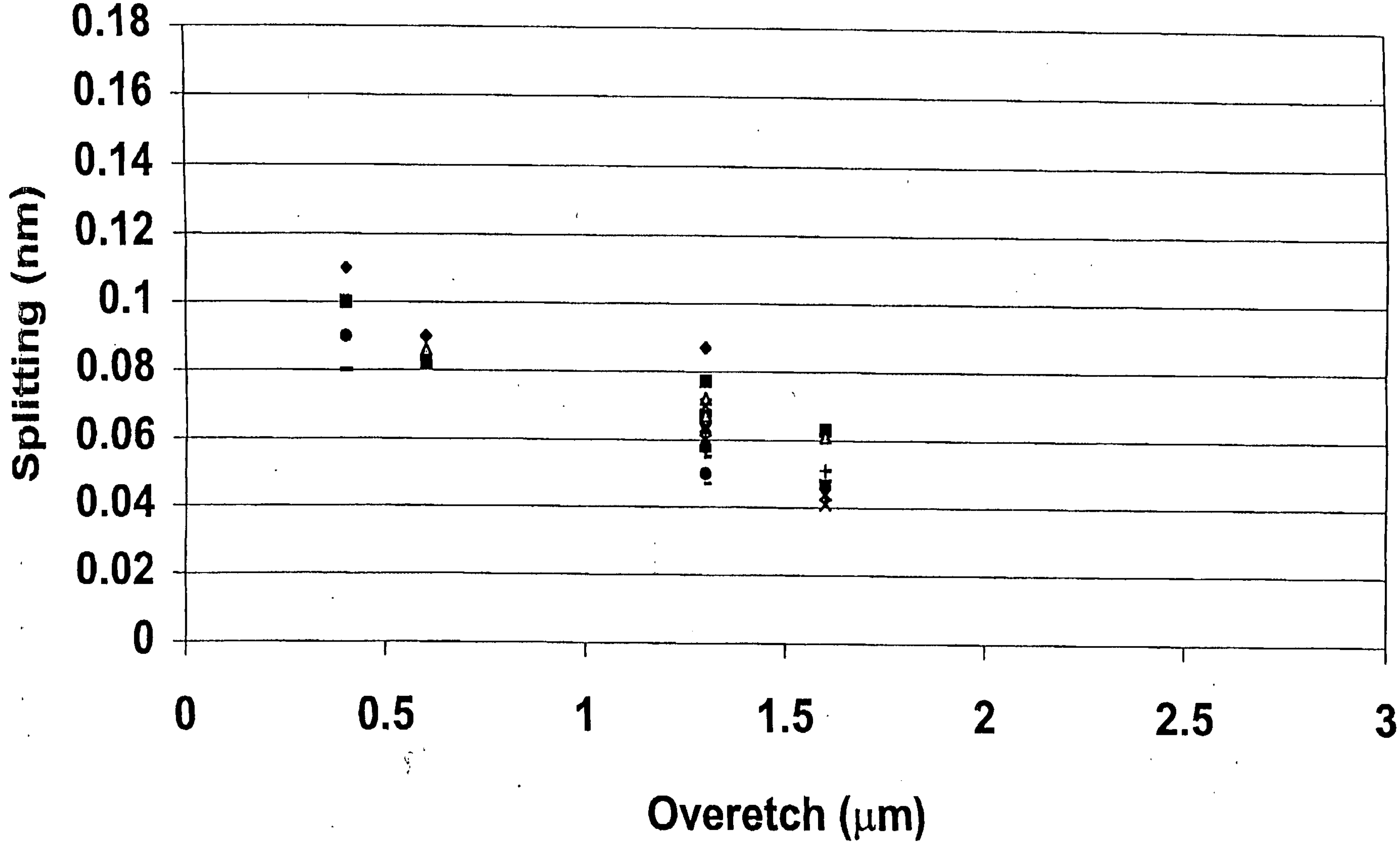

0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Splitting (nm)
0
0.5
1
1.5
2
2.5
3
Overetch (μm)

Fig. 3

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